# $\Delta(1600)$ $P_{33}$

$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$ Status: ***

Most of the results published before 1975 are now obsolete and have been omitted. They may be found in our 1982 edition, Physics Letters **111B** (1982).

The various analyses are not in good agreement.

## $\Delta(1600)$ BREIT-WIGNER MASS

| *VALUE* (MeV) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **1550 to 1700 (≈ 1600) OUR ESTIMATE** | | | | |
| 1706±10 | MANLEY | 92 | IPWA | $\pi N \to \pi N$ & $N\pi\pi$ |
| 1600±50 | CUTKOSKY | 80 | IPWA | $\pi N \to \pi N$ |
| 1522±13 | HOEHLER | 79 | IPWA | $\pi N \to \pi N$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| 1667± 1 | PENNER | 02C | DPWA | Multichannel |
| 1687±44 | VRANA | 00 | DPWA | Multichannel |
| 1672±15 | ARNDT | 96 | IPWA | $\gamma N \to \pi N$ |
| 1706 | LI | 93 | IPWA | $\gamma N \to \pi N$ |
| 1690 | BARNHAM | 80 | IPWA | $\pi N \to N\pi\pi$ |
| 1560 | [1] LONGACRE | 77 | IPWA | $\pi N \to N\pi\pi$ |
| 1640 | [2] LONGACRE | 75 | IPWA | $\pi N \to N\pi\pi$ |

## $\Delta(1600)$ BREIT-WIGNER WIDTH

| *VALUE* (MeV) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **250 to 450 (≈ 350) OUR ESTIMATE** | | | | |
| 430± 73 | MANLEY | 92 | IPWA | $\pi N \to \pi N$ & $N\pi\pi$ |
| 300±100 | CUTKOSKY | 80 | IPWA | $\pi N \to \pi N$ |
| 220± 40 | HOEHLER | 79 | IPWA | $\pi N \to \pi N$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| 397± 10 | PENNER | 02C | DPWA | Multichannel |
| 493± 75 | VRANA | 00 | DPWA | Multichannel |
| 315± 20 | ARNDT | 96 | IPWA | $\gamma N \to \pi N$ |
| 215 | LI | 93 | IPWA | $\gamma N \to \pi N$ |
| 250 | BARNHAM | 80 | IPWA | $\pi N \to N\pi\pi$ |
| 180 | [1] LONGACRE | 77 | IPWA | $\pi N \to N\pi\pi$ |
| 300 | [2] LONGACRE | 75 | IPWA | $\pi N \to N\pi\pi$ |

## $\Delta(1600)$ POLE POSITION

### REAL PART

| *VALUE* (MeV) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **1500 to 1700 (≈ 1600) OUR ESTIMATE** | | | | |
| 1675 | ARNDT | 95 | DPWA | $\pi N \to N\pi$ |
| 1550 | [3] HOEHLER | 93 | SPED | $\pi N \to \pi N$ |
| 1550±40 | CUTKOSKY | 80 | IPWA | $\pi N \to \pi N$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | | | |
|---|---|---|---|---|
| 1599 | VRANA | 00 | DPWA | Multichannel |
| 1612 | ARNDT | 91 | DPWA | $\pi N \to \pi N$ Soln SM90 |
| 1609 or 1610 | [4] LONGACRE | 78 | IPWA | $\pi N \to N\pi\pi$ |
| 1541 or 1542 | [1] LONGACRE | 77 | IPWA | $\pi N \to N\pi\pi$ |

### $-2\times$IMAGINARY PART

| *VALUE* (MeV) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **200 to 400 ($\approx$ 300) OUR ESTIMATE** | | | | |
| 386 | ARNDT | 95 | DPWA | $\pi N \to N\pi$ |
| $200\pm60$ | CUTKOSKY | 80 | IPWA | $\pi N \to \pi N$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | | | |
|---|---|---|---|---|
| 312 | VRANA | 00 | DPWA | Multichannel |
| 230 | ARNDT | 91 | DPWA | $\pi N \to \pi N$ Soln SM90 |
| 323 or 325 | [4] LONGACRE | 78 | IPWA | $\pi N \to N\pi\pi$ |
| 178 or 178 | [1] LONGACRE | 77 | IPWA | $\pi N \to N\pi\pi$ |

## $\Delta(1600)$ ELASTIC POLE RESIDUE

### MODULUS $|r|$

| *VALUE* (MeV) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| 52 | ARNDT | 95 | DPWA | $\pi N \to N\pi$ |
| $17\pm4$ | CUTKOSKY | 80 | IPWA | $\pi N \to \pi N$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | | | |
|---|---|---|---|---|
| 16 | ARNDT | 91 | DPWA | $\pi N \to \pi N$ Soln SM90 |

### PHASE $\theta$

| *VALUE* (°) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| + 14 | ARNDT | 95 | DPWA | $\pi N \to N\pi$ |
| $-150\pm30$ | CUTKOSKY | 80 | IPWA | $\pi N \to \pi N$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | | | |
|---|---|---|---|---|
| − 73 | ARNDT | 91 | DPWA | $\pi N \to \pi N$ Soln SM90 |

## $\Delta(1600)$ DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction ($\Gamma_i/\Gamma$) |
|---|---|---|
| $\Gamma_1$ | $N\pi$ | 10–25 % |
| $\Gamma_2$ | $\Sigma K$ | |
| $\Gamma_3$ | $N\pi\pi$ | 75–90 % |
| $\Gamma_4$ | $\Delta\pi$ | 40–70 % |
| $\Gamma_5$ | $\Delta(1232)\pi$, $P$-wave | |
| $\Gamma_6$ | $\Delta(1232)\pi$, $F$-wave | |
| $\Gamma_7$ | $N\rho$ | <25 % |

| | | |
|---|---|---|
| $\Gamma_8$ | $N\rho$, $S$=1/2, $P$-wave | |
| $\Gamma_9$ | $N\rho$, $S$=3/2, $P$-wave | |
| $\Gamma_{10}$ | $N\rho$, $S$=3/2, $F$-wave | |
| $\Gamma_{11}$ | $N(1440)\pi$ | 10–35 % |
| $\Gamma_{12}$ | $N(1440)\pi$, $P$-wave | |
| $\Gamma_{13}$ | $N\gamma$ | 0.001–0.02 % |
| $\Gamma_{14}$ | $N\gamma$, helicity=1/2 | 0.0–0.02 % |
| $\Gamma_{15}$ | $N\gamma$, helicity=3/2 | 0.001–0.005 % |

## $\Delta(1600)$ BRANCHING RATIOS

### $\Gamma(N\pi)/\Gamma_{total}$ $\Gamma_1/\Gamma$

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|
| **0.10 to 0.25 OUR ESTIMATE** | | | | |
| 0.12±0.02 | MANLEY | 92 | IPWA | $\pi N \to \pi N$ & $N\pi\pi$ |
| 0.18±0.04 | CUTKOSKY | 80 | IPWA | $\pi N \to \pi N$ |
| 0.21±0.06 | HOEHLER | 79 | IPWA | $\pi N \to \pi N$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| 0.13±0.01 | PENNER | 02C | DPWA | Multichannel |
| 0.28±0.05 | VRANA | 00 | DPWA | Multichannel |

### $(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1600) \to \Sigma K$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

| VALUE | | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **−0.36 to −0.28 OUR ESTIMATE** | | | | | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| 0.006 to 0.042 | [5] | DEANS | 75 | DPWA | $\pi N \to \Sigma K$ |

Note: Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ $S_{31}$ coupling to $\Delta(1232)\pi$.

### $(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1600) \to \Delta(1232)\pi$, $P$-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

| VALUE | | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **+0.27 to +0.33 OUR ESTIMATE** | | | | | |
| +0.29±0.02 | | MANLEY | 92 | IPWA | $\pi N \to \pi N$ & $N\pi\pi$ |
| +0.24±0.05 | | BARNHAM | 80 | IPWA | $\pi N \to N\pi\pi$ |
| +0.34 | [1,6] | LONGACRE | 77 | IPWA | $\pi N \to N\pi\pi$ |
| +0.30 | [2] | LONGACRE | 75 | IPWA | $\pi N \to N\pi\pi$ |

### $\Gamma(\Delta(1232)\pi, P\text{-wave})/\Gamma_{total}$ $\Gamma_5/\Gamma$

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|
| 0.59±0.10 | VRANA | 00 | DPWA | Multichannel |

### $(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1600) \to \Delta(1232)\pi$, $F$-wave $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

| VALUE | | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **−0.15 to −0.03 OUR ESTIMATE** | | | | | |
| −0.07 | [1,6] | LONGACRE | 77 | IPWA | $\pi N \to N\pi\pi$ |

### $(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1600) \to N\rho$, $S$=1/2, $P$-wave $(\Gamma_1\Gamma_8)^{1/2}/\Gamma$

| VALUE | | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| +0.10 | [1,6] | LONGACRE | 77 | IPWA | $\pi N \to N\pi\pi$ |

### $(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1600) \to N\rho$, $S$=3/2, $P$-wave $(\Gamma_1\Gamma_9)^{1/2}/\Gamma$

| VALUE | | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| +0.10 | [1,6] | LONGACRE | 77 | IPWA | $\pi N \to N\pi\pi$ |

### $(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to \Delta(1600) \to N(1440)\pi$, $P$-wave $(\Gamma_1\Gamma_{12})^{1/2}/\Gamma$

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|
| **+0.15 to +0.23 OUR ESTIMATE** | | | | |
| +0.16±0.02 | MANLEY | 92 | IPWA | $\pi N \to \pi N$ & $N\pi\pi$ |
| +0.23±0.04 | BARNHAM | 80 | IPWA | $\pi N \to N\pi\pi$ |

### $\Gamma(N(1440)\pi)/\Gamma_{total}$ $\Gamma_{11}/\Gamma$

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|
| 0.13±0.04 | VRANA | 00 | DPWA | Multichannel |

## $\Delta(1600)$ PHOTON DECAY AMPLITUDES

### $\Delta(1600) \to N\gamma$, helicity-1/2 amplitude $A_{1/2}$

| VALUE ($GeV^{-1/2}$) | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|
| **−0.023±0.020 OUR ESTIMATE** | | | | |
| −0.018±0.015 | ARNDT | 96 | IPWA | $\gamma N \to \pi N$ |
| −0.039±0.030 | CRAWFORD | 83 | IPWA | $\gamma N \to \pi N$ |
| −0.046±0.013 | AWAJI | 81 | DPWA | $\gamma N \to \pi N$ |
| 0.005±0.020 | CRAWFORD | 80 | DPWA | $\gamma N \to \pi N$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| 0.0 | PENNER | 02D | DPWA | Multichannel |
| −0.026±0.002 | LI | 93 | IPWA | $\gamma N \to \pi N$ |
| −0.200 | [7] WADA | 84 | DPWA | Compton scattering |
| 0.000±0.030 | BARBOUR | 78 | DPWA | $\gamma N \to \pi N$ |
| 0.0 ±0.020 | FELLER | 76 | DPWA | $\gamma N \to \pi N$ |

### $\Delta(1600) \to N\gamma$, helicity-3/2 amplitude $A_{3/2}$

| VALUE ($GeV^{-1/2}$) | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|
| **−0.009±0.021 OUR ESTIMATE** | | | | |
| −0.025±0.015 | ARNDT | 96 | IPWA | $\gamma N \to \pi N$ |
| −0.013±0.014 | CRAWFORD | 83 | IPWA | $\gamma N \to \pi N$ |
| 0.025±0.031 | AWAJI | 81 | DPWA | $\gamma N \to \pi N$ |
| −0.009±0.020 | CRAWFORD | 80 | DPWA | $\gamma N \to \pi N$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| −0.024 | PENNER | 02D | DPWA | Multichannel |
| −0.016±0.002 | LI | 93 | IPWA | $\gamma N \to \pi N$ |
| 0.023 | WADA | 84 | DPWA | Compton scattering |
| 0.000±0.045 | BARBOUR | 78 | DPWA | $\gamma N \to \pi N$ |
| 0.0 ±0.015 | FELLER | 76 | DPWA | $\gamma N \to \pi N$ |

## Δ(1600) FOOTNOTES

[1] LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to $\pi N \to N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis. The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.

[2] From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.

[3] See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of $N$ and $\Delta$ resonances as determined from Argand diagrams of $\pi N$ elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.

[4] LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to $\pi N \to N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.

[5] The range given is from the four best solutions. DEANS 75 disagrees with $\pi^+ p \to \Sigma^+ K^+$ data of WINNIK 77 around 1920 MeV.

[6] LONGACRE 77 considers this coupling to be well determined.

[7] WADA 84 is inconsistent with other analyses — see the Note on $N$ and $\Delta$ Resonances.

## Δ(1600) REFERENCES

For early references, see Physics Letters **111B** 70 (1982).


| | | | | |
|---|---|---|---|---|
| PENNER | 02C | PR C66 055211 | G. Penner, U. Mosel | (GIES) |
| PENNER | 02D | PR C66 055212 | G. Penner, U. Mosel | (GIES) |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, T.-S.H. Lee | (PITT+) |
| ARNDT | 96 | PR C53 430 | R.A. Arndt, I.I. Strakovsky, R.L. Workman | (VPI) |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt *et al.* | (VPI, BRCO) |
| HOEHLER | 93 | $\pi N$ Newsletter 9 1 | G. Hohler | (KARL) |
| LI | 93 | PR C47 2759 | Z.J. Li *et al.* | (VPI) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KENT) IJP |
| Also | 84 | PR D30 904 | D.M. Manley *et al.* | (VPI) |
| ARNDT | 91 | PR D43 2131 | R.A. Arndt *et al.* | (VPI, TELE) IJP |
| WADA | 84 | NP B247 313 | Y. Wada *et al.* | (INUS) |
| CRAWFORD | 83 | NP B211 1 | R.L. Crawford, W.T. Morton | (GLAS) |
| PDG | 82 | PL 111B | M. Roos *et al.* | (HELS, CIT, CERN) |
| AWAJI | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | (NAGO) |
| Also | 82 | NP B197 365 | K. Fujii *et al.* | (NAGO) |
| BARNHAM | 80 | NP B168 243 | K.W.J. Barnham *et al.* | (LOIC) |
| CRAWFORD | 80 | Toronto Conf. 107 | R.L. Crawford | (GLAS) |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky *et al.* | (CMU, LBL) IJP |
| Also | 79 | PR D20 2839 | R.E. Cutkosky *et al.* | (CMU, LBL) IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler *et al.* | (KARLT) IJP |
| Also | 80 | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| BARBOUR | 78 | NP B141 253 | I.M. Barbour, R.L. Crawford, N.H. Parsons | (GLAS) |
| LONGACRE | 78 | PR D17 1795 | R.S. Longacre *et al.* | (LBL, SLAC) |
| LONGACRE | 77 | NP B122 493 | R.S. Longacre, J. Dolbeau | (SACL) IJP |
| Also | 76 | NP B108 365 | J. Dolbeau *et al.* | (SACL) IJP |
| WINNIK | 77 | NP B128 66 | M. Winnik *et al.* | (HAIF) I |
| FELLER | 76 | NP B104 219 | P. Feller *et al.* | (NAGO, OSAK) IJP |
| DEANS | 75 | NP B96 90 | S.R. Deans *et al.* | (SFLA, ALAH) IJP |
| LONGACRE | 75 | PL 55B 415 | R.S. Longacre *et al.* | (LBL, SLAC) IJP |